2014-10-02

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Hattar, Khalid Mikhiel, et al. Mechanical Response of Self-Ion Irradiated Single Crystal FCC Micropillars. No. SAND2014-17695PE. Sandia National Lab.(SNL-NM), Albuquerque, NM (United States), 2014.

http://hdl.handle.net/10945/62865

Mechanical Response of Self-Ion Irradiated, Single Crystal, FCC Micropillars

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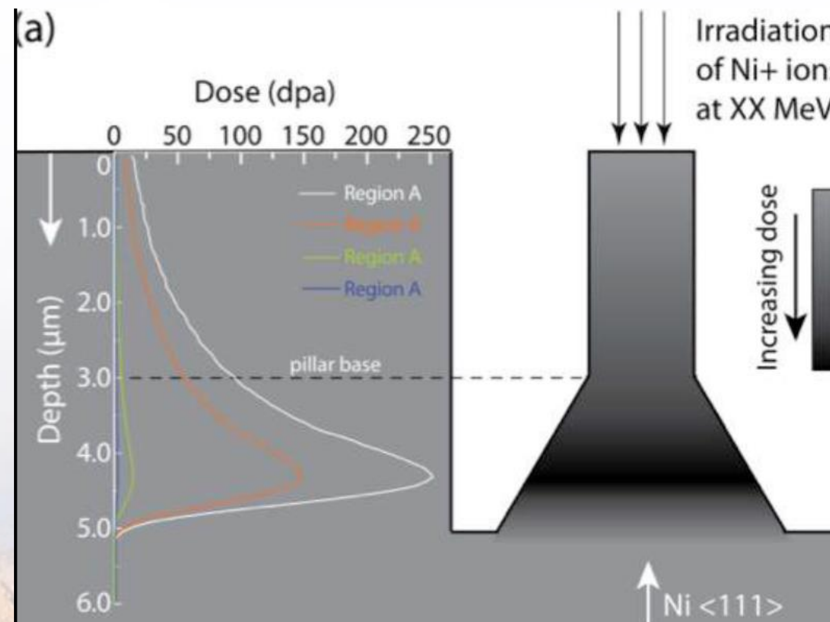
October 2, 2014



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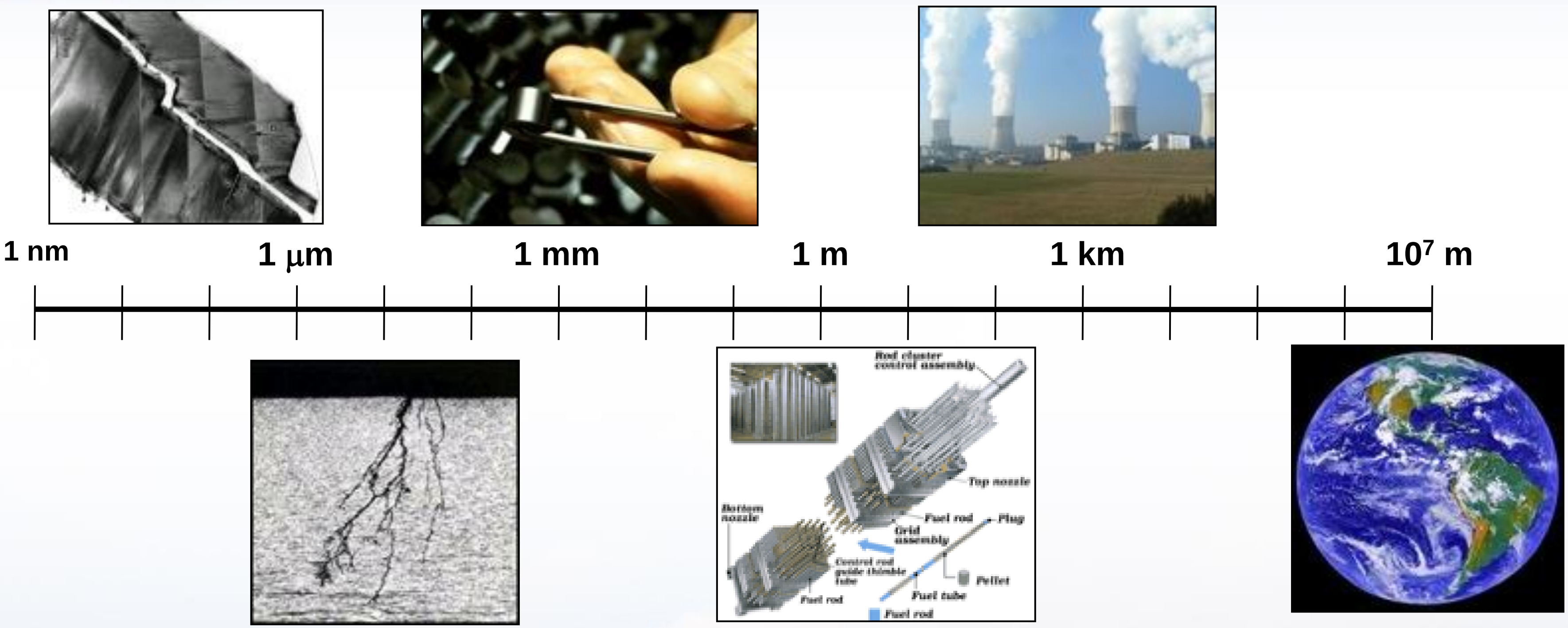
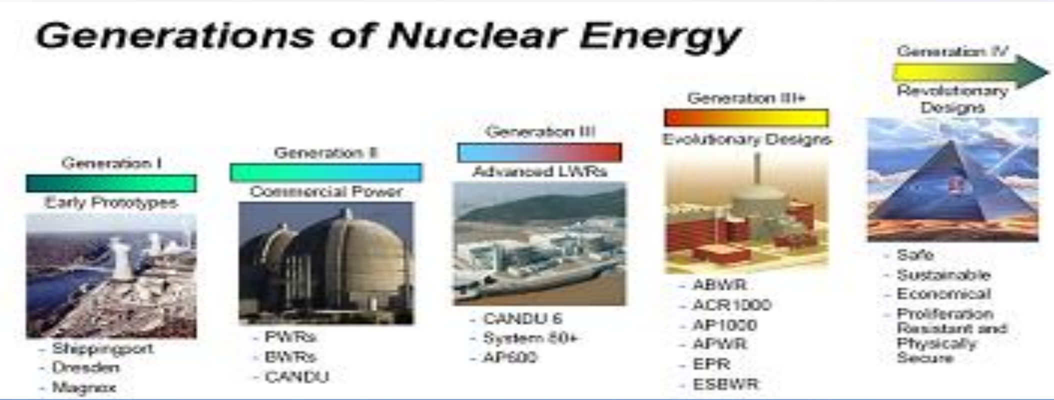
Investigating the nm Scale to Understand the km Scale Response of Materials in the Extremes



- Advanced Materials are Needed
- Several Theories exist for the desired microstructure
- New materials have been made
- Current Neutron fluxes require decades for testing



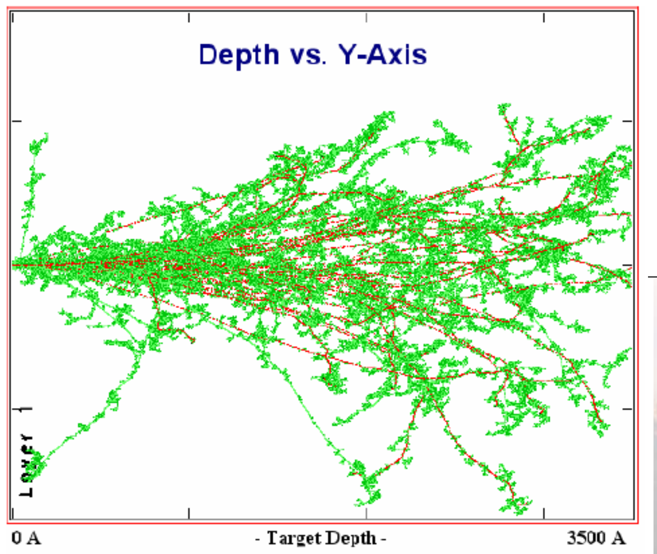
Length Scale Limitations due to Ion Irradiation

Advantages

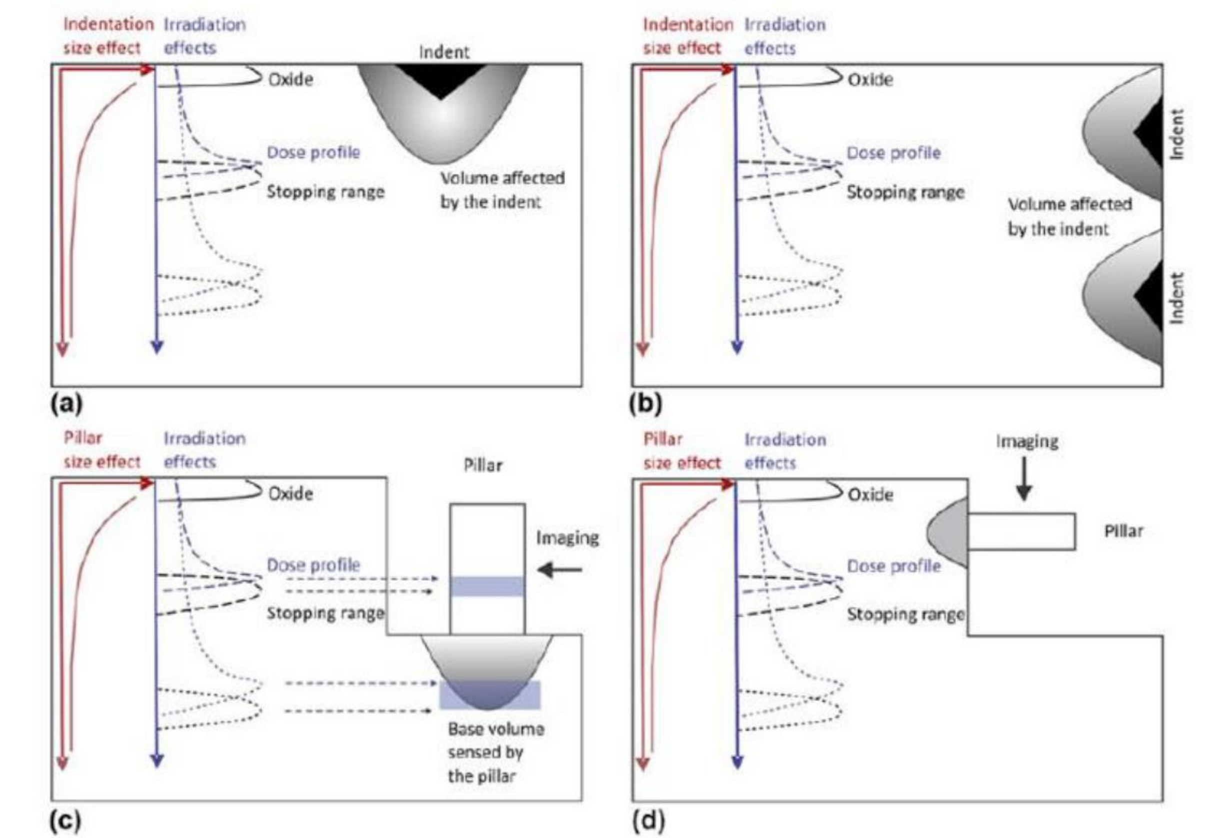
- High total damage in short periods of time
- Relatively accessible

Disadvantages

- Unknown effect of damage rate
- Limited to small volumes
- Heterogeneous microstructure



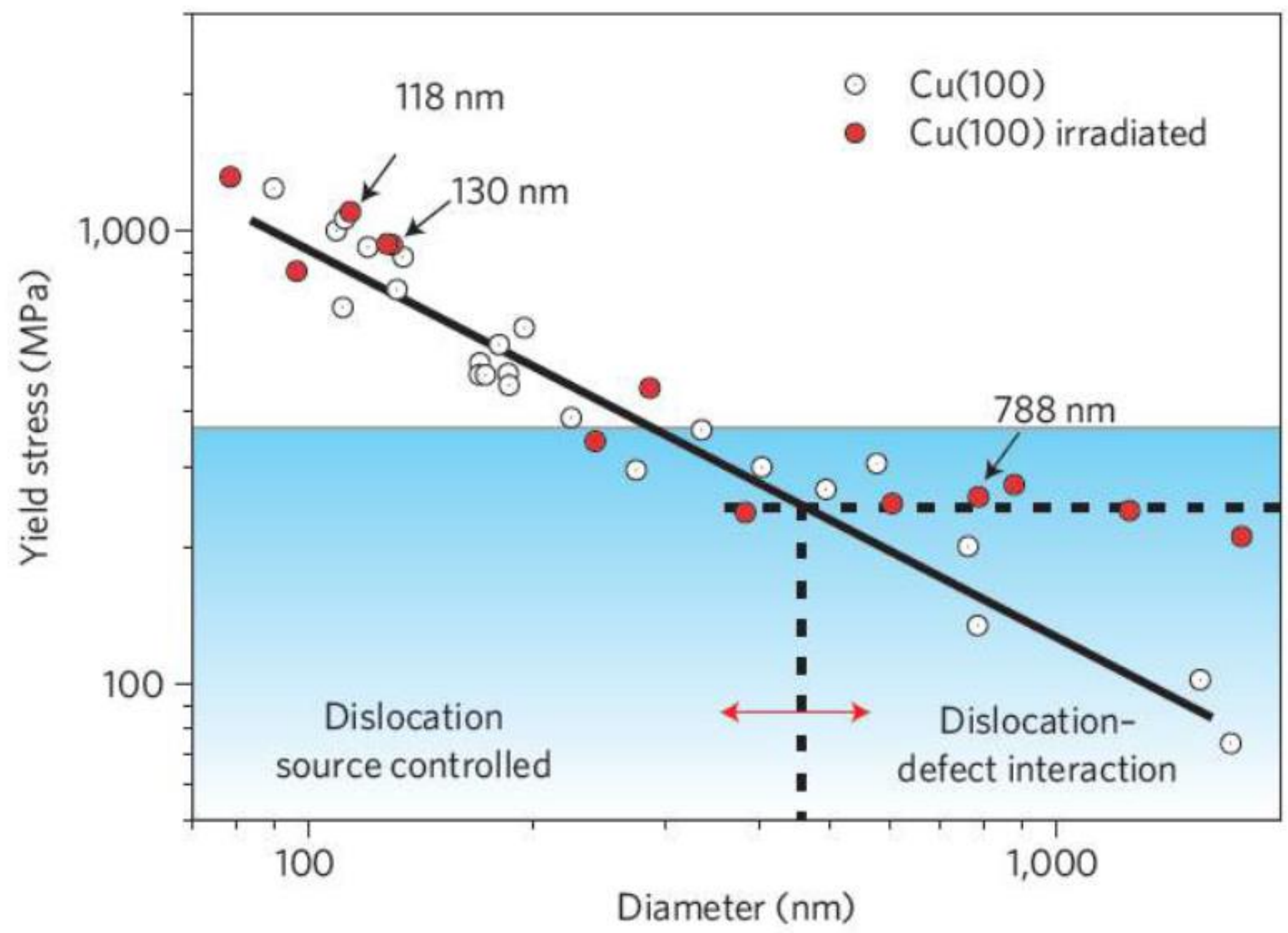
SRIM



Kiener et al. JMR (2012)

Key point

How can we decouple size effects from irradiation-induced effects



Kiener et al. Nat. Mater. (2011)

The increase in yield strength associated with the decreasing of pillar size below ~500 nm makes it difficult to identify the effects of radiation damage in small pillars.

Micropillar Compression Experiments

Sample Preparation:

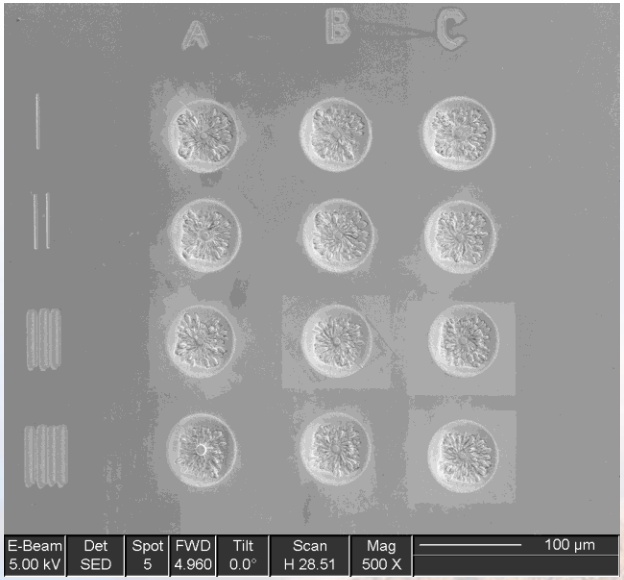
- Copper single crystals (FCC)
- Different crystallographic orientations: (100), (110), and (111)
- Self-ion Implants at 30 MeV to
- 0 (control), 50 dpa, and 100 dpa.

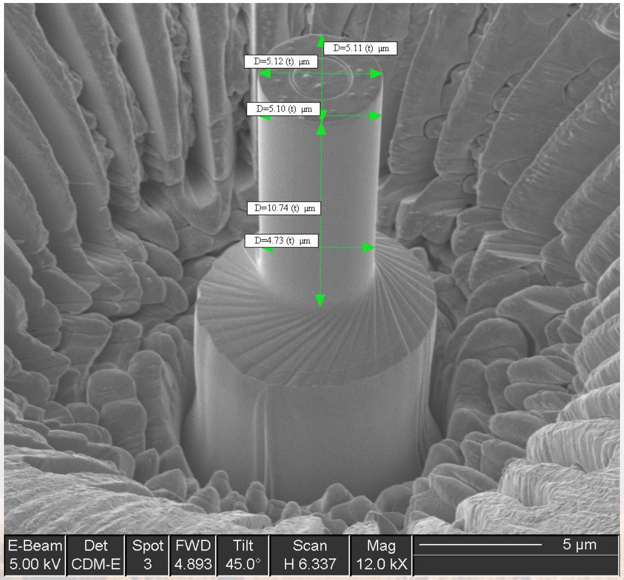
Pillar Manufacturing:

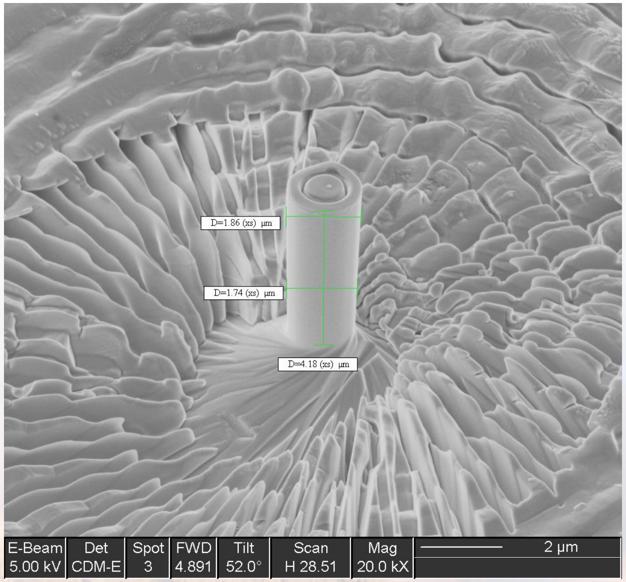
- We employ Uchic's FIB lathe machining process for straight-walled cylinders.
- Array of at least 9 nominally identical pillars tested per condition to assess statistical variability.
- Height varies from 4 µm to 10 µm

Compression Testing:

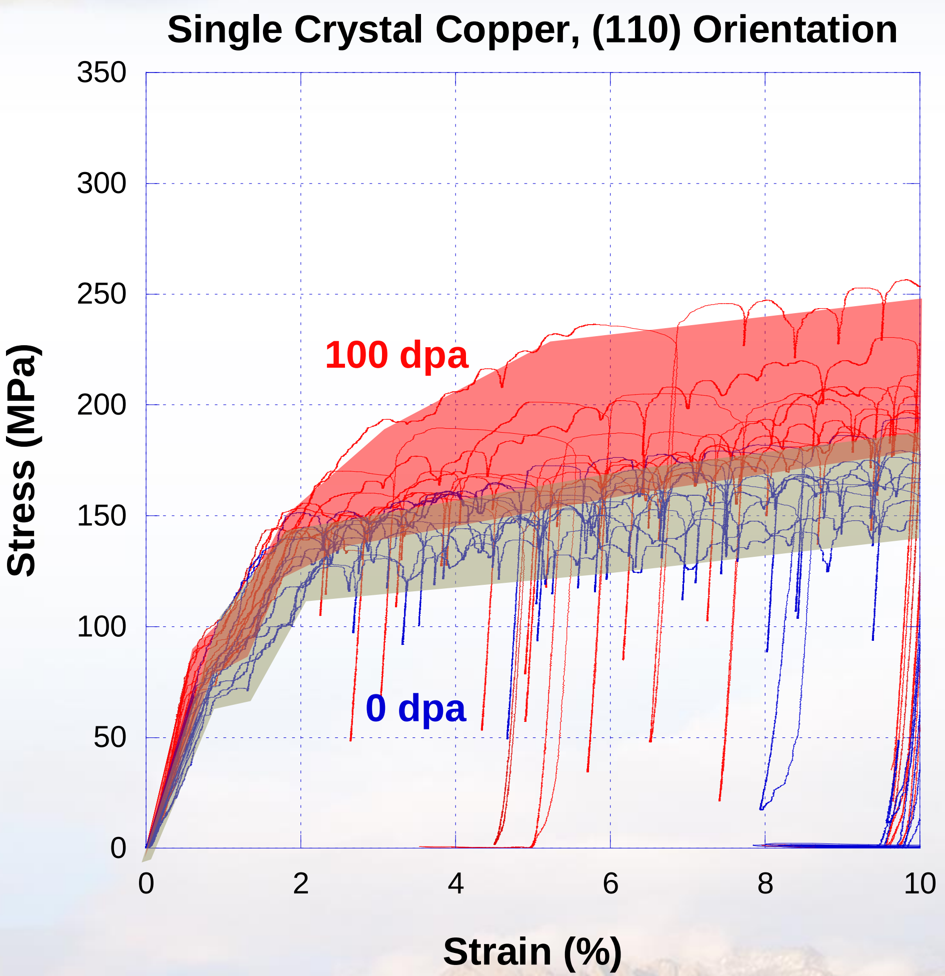
- Hysitron Performech Nanoindenter permits <1 nm and <1 µN resolution.
- 25 µm flat ended cone indenter in feedback displacement control, rather than typical force control.
- Pillars compressed 10% strain at a strain rate of $0.025\ s^{-1}$.

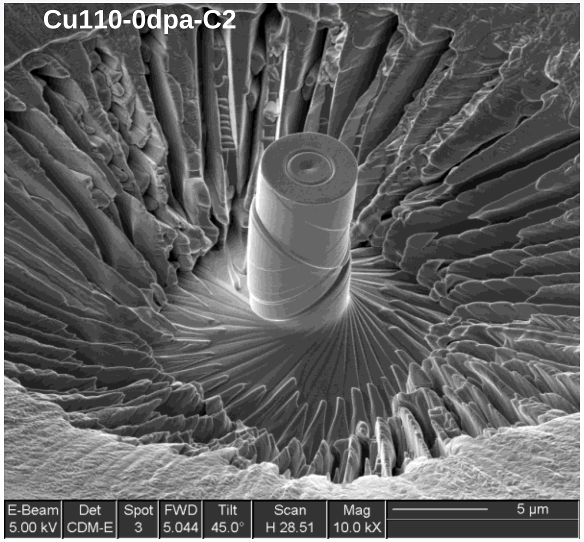


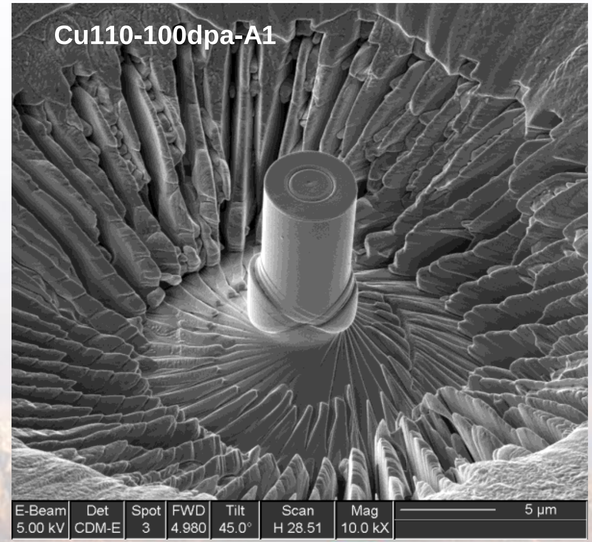




Large Micropillar Compression







Minimal difference between the control and irradiated 10 µm-tall pillars. Slip occurred in the bottom fraction of the pillars.

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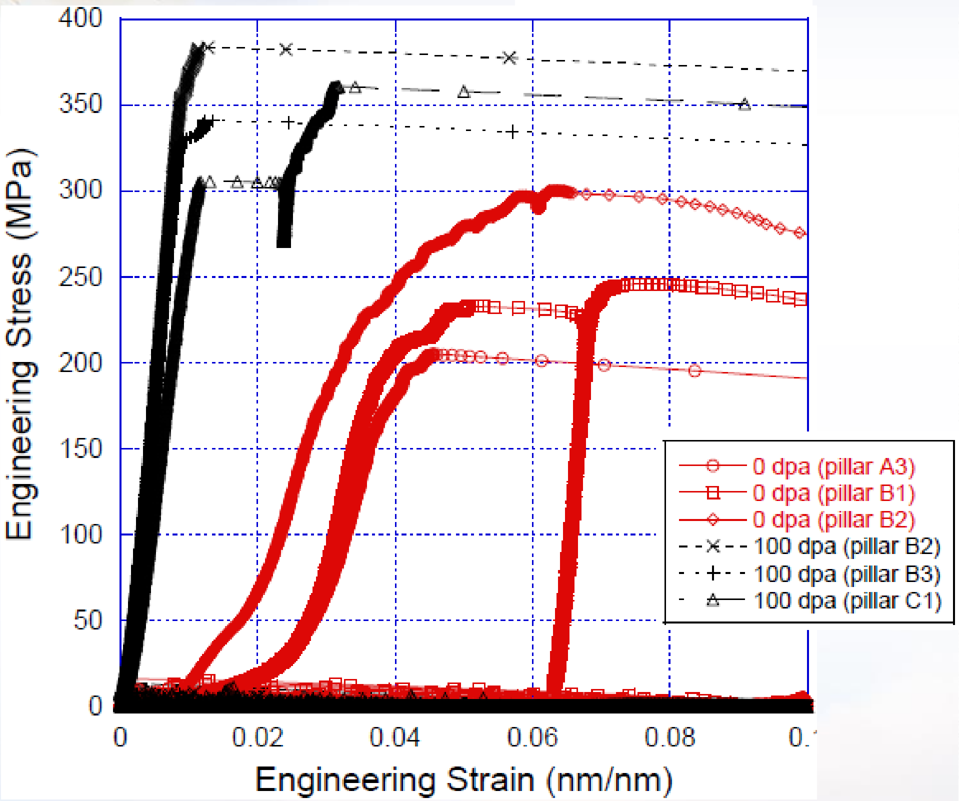
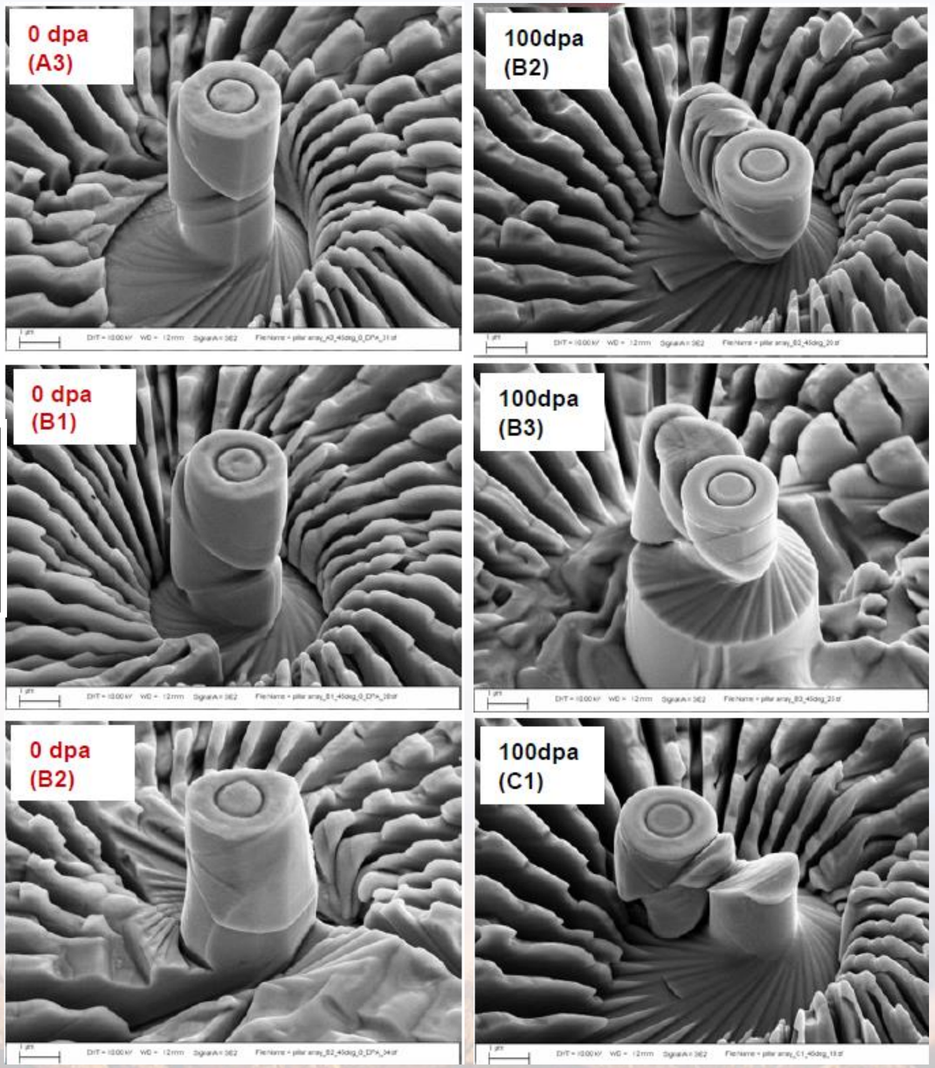
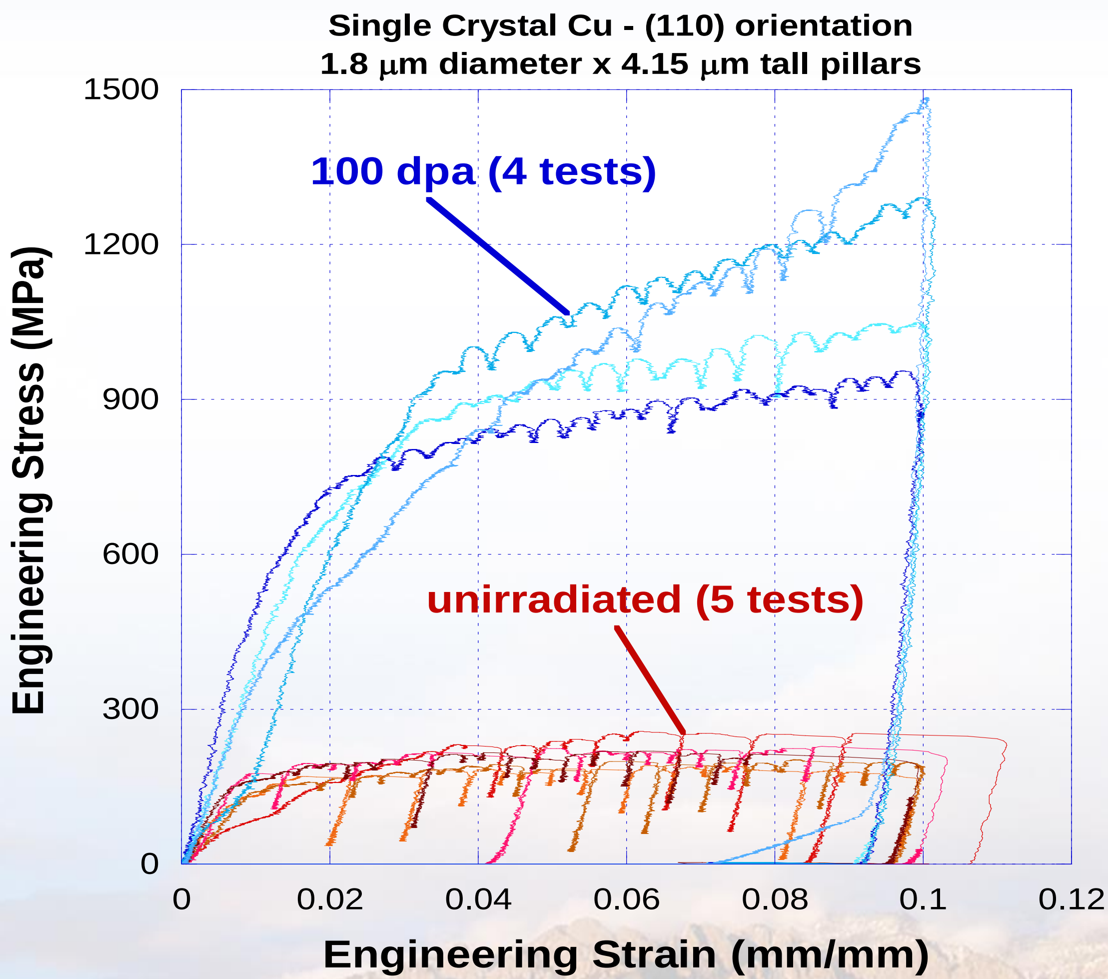
Intermediate Micropillar Compression

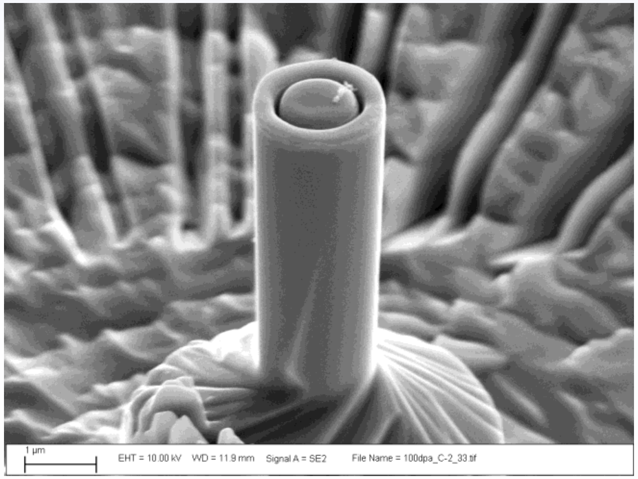


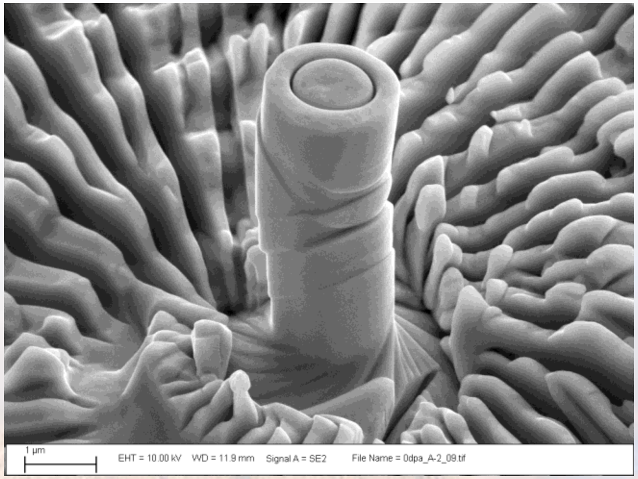


5 µm-tall pillars show greater distinction with catastrophic failure

Small Micropillar Compression







Initial tests indicate that the 4 μm-tall pillars are 5 times stronger and show no signs of slip band formation

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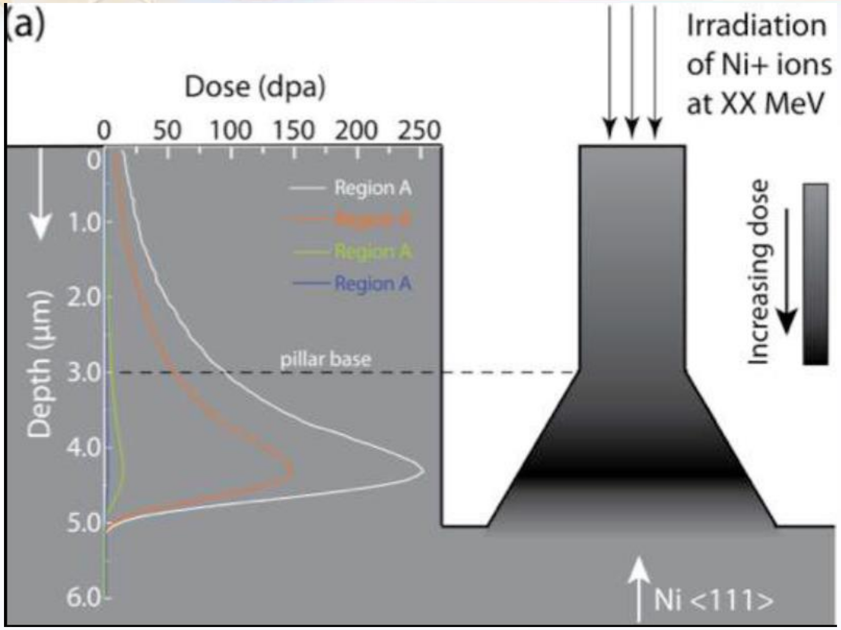
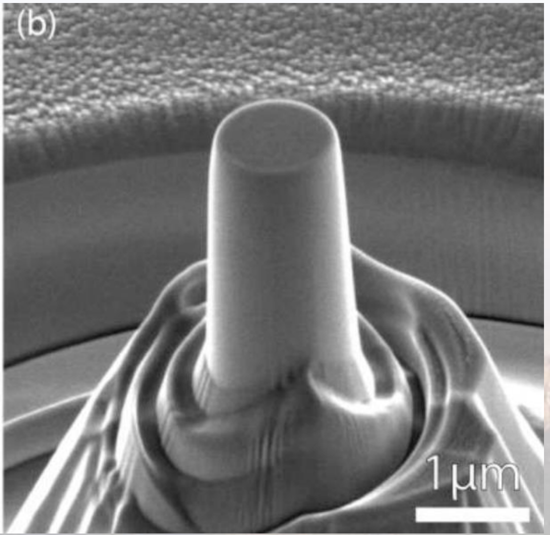
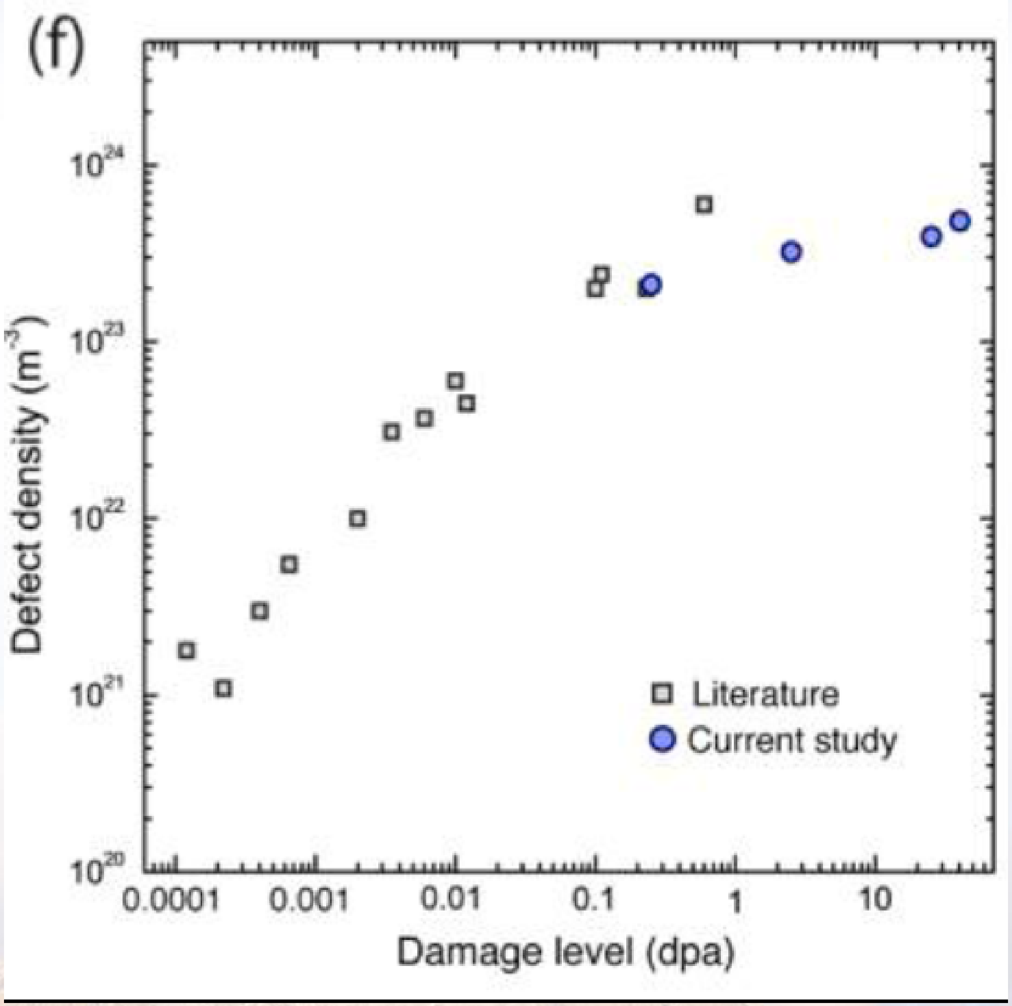
Ni implantation of <111> Ni

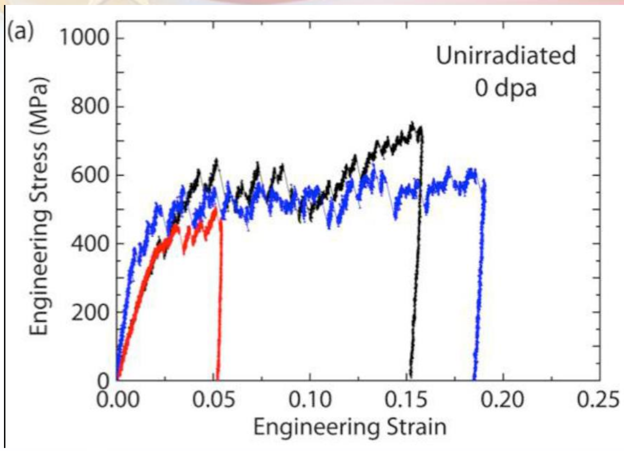






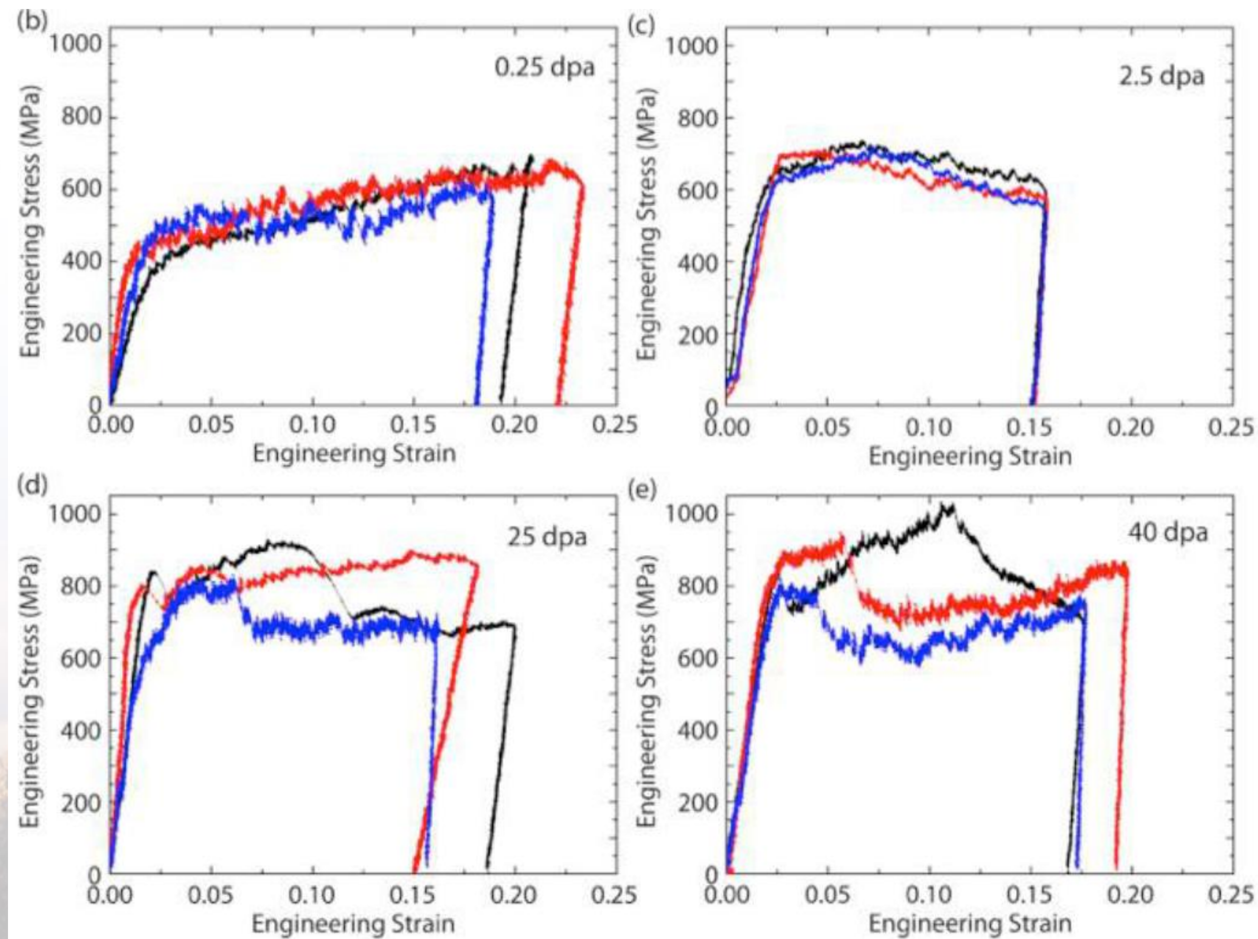
We can create similar Ni pillars and through SRIM modeling and TEM characterization, we can tailor and verify the defect structure.

Comparison of the Mechanical Response as a Function of Dose

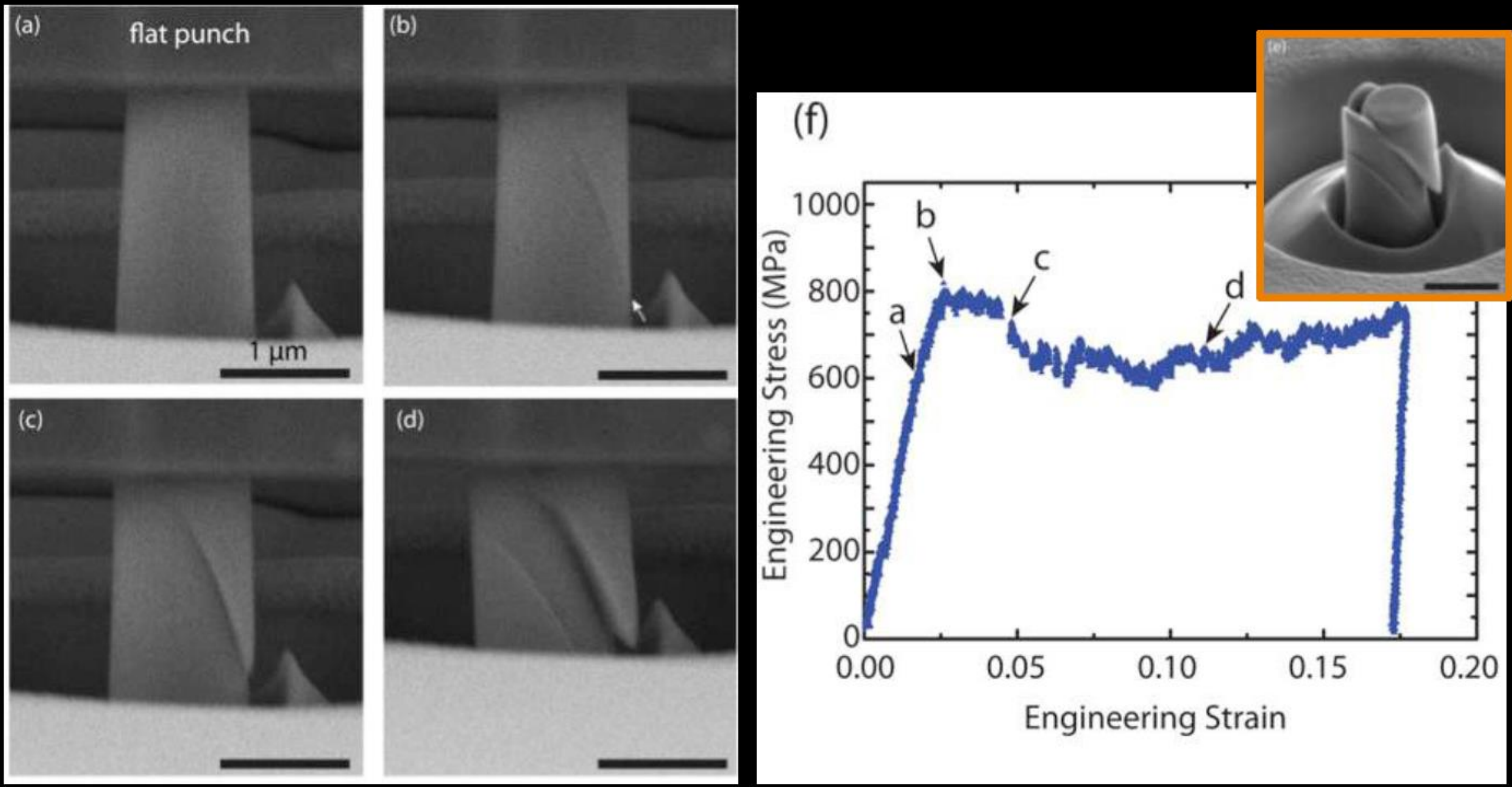


1) Strength increases with increasing damage

2) Intermittency changes dramatically and non-monotonically



In situ SEM Permits Correlation between Physical Slip and Intermittency in Stress-Strain Curve



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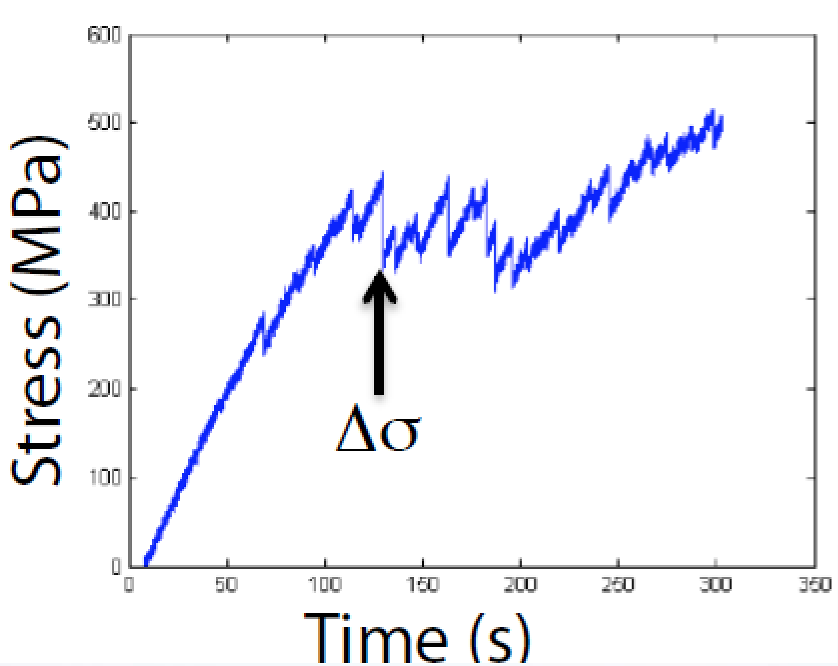
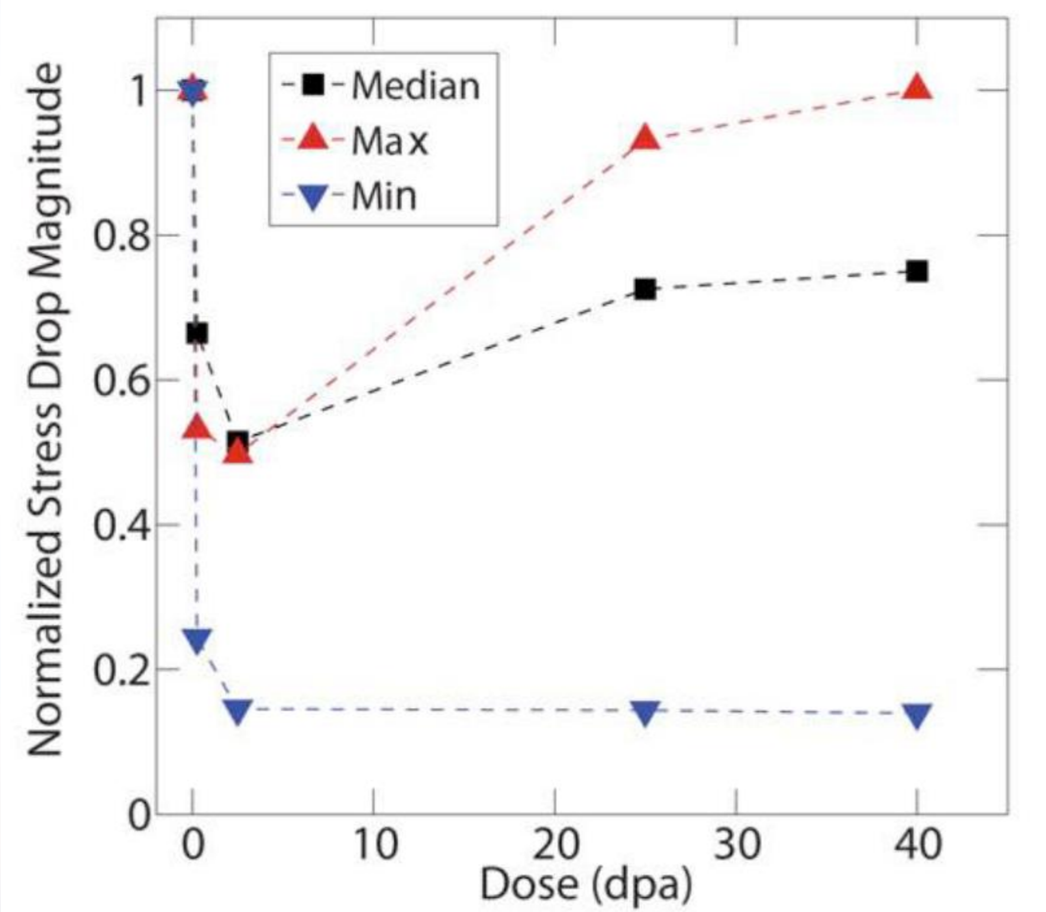
Quantification of Stress Drops

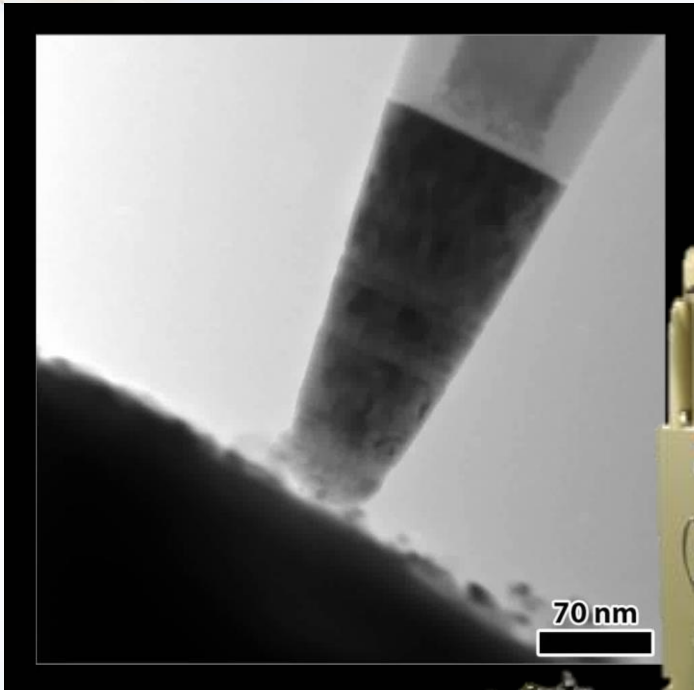


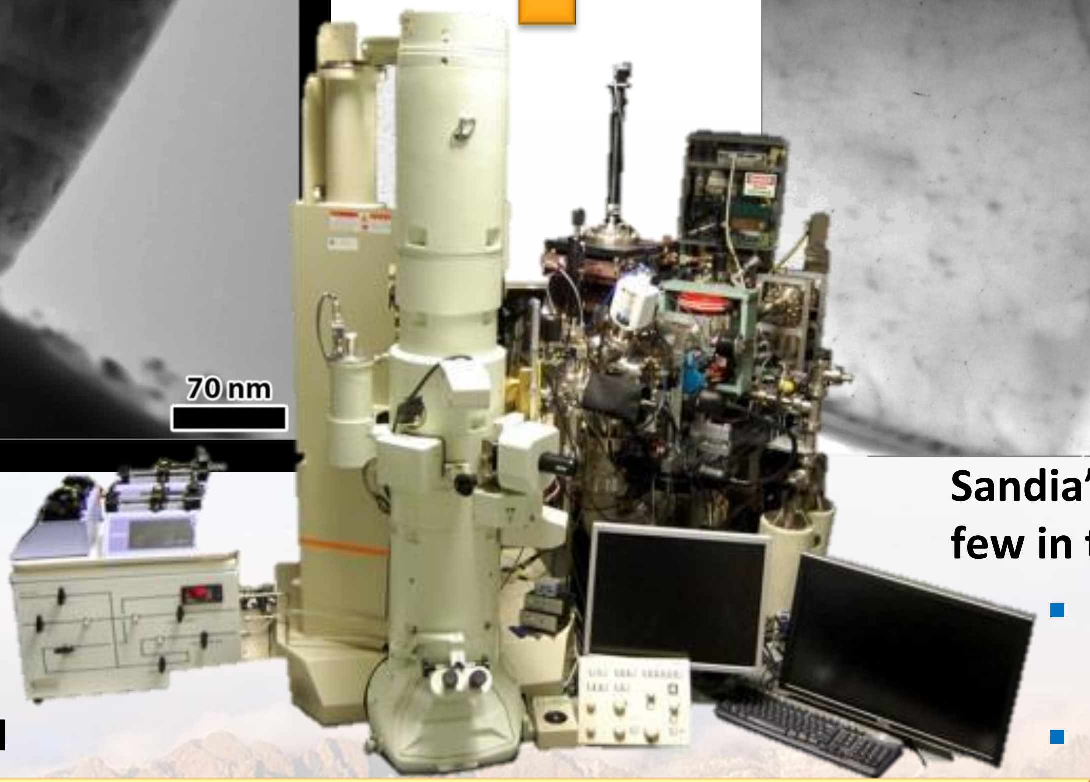


- Minimum stress drops monotonically decreases with in increasing dose.
- Maximum stress drops non-monotonically with increasing dose
- Provides insight into the role of dislocation-free channels on the mechanical response

Future Direction

Collaborator: D.L. Buller, J.A. Scott, D.C. Bufford & W.M. Mook





- 0.5 nm/s
- Trapezoid load function
- 60s load/60s hold/60s unload

Sandia's I^3TEM is one of a few in the world

- *In situ* irradiation from H to Au
- *In situ* gas implantation

Create single crystal pillars and study the results of irradiation damage on mechanical properties and potential radiation induced creep